Vol. XXXV. JULY, 1896.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

No. 773.

COST OF SEWER CONSTRUCTION, DENVER, COLO.

W. W. FOLLETT, M. Am. Soc. C. E.

PRESENTED JANUARY 8TH, 1896.

WITH DISCUSSION.

The city of Denver, Colo., containing with its suburbs some 130 000 or more people, is built on both banks of the South Platte River, the course of which is here approximately northeast. The main portion of the city is on the south side of the river. The sewerage system has grown with the town, all sewage being discharged into the channel of the South Platte River. Reference to the map (Fig. 1) will show that prior to the construction of the intercepting sewer below Twenty-sixth Street house sewage from the south was discharged into the river at Thirty-sixth Street by the Downing Avenue sewer, at Thirty-first Street by the Thirty-first Street sewer, and at Thirty-fourth Street by a wooden box from Twenty-sixth Street, not shown on the map. Both Downing Avenue and Thirty-first Street delivered small quantities of sewage, the main body coming from the Delgany Street sewer, the end of which was at Twenty-sixth Street. Here some 30 second-feet of sewage, plus a large amount of storm water during short periods of time, had to be taken care of.

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During the early spring of 1894 Mr. E. P. Martin, Chief Engineer of the Board of Public Works, designed an extension of the Delgany Street sewer (see Fig. 1) to serve as a main intercepting sewer, carrying all sewage from the south down the river to the outskirts of the city, and to be built on such a gradient as to eventually reach the surface of the ground, some 3 miles below Twenty-sixth Street, at which point the sewage would become available for irrigation and be kept from the channel of the river. This ultimate disposal of the sewage is rendered necessary from the fact that practically the whole summer flow of the river is taken out into irrigation ditches above Denver, and the channel in September is nearly dry. Sewage collects on sand bars and becomes a menace to health.

In May, 1894, the Board of Public Works, consisting of Arthur C. Harris, president, T. B. Buchanan and C. W. Rhodes, determined to build some 8 300 ft. of the Delgany sewer extension—as much as the funds at their disposal justified—and they decided to do the work by day labor, instead of by contract.

It is the purpose of the author to present statements of actual cost of completed work, together with such data as to wages paid, cost of materials used, etc., as will enable members to compare the cost of this work by day labor with contract prices.

The drainage areas and the estimated amounts of house sewage and storm water from them are as follows:

House Sewage.

	Acres.	Second-feet.
Above Twenty-sixth Street in main	6 200	77.8
Entering at Twenty-sixth Street	320	3.7
Entering at Thirty-first Street	1 545	18.0
Entering at Thirty-sixth Street	2 520	29.4
Total	10 585	128.9

Storm Water.

	Acres.	Second-feet.
Above Twenty-sixth Street	255	159.6
Entering at Twenty-sixth Street	45	28.8
Total	300	188.4

Storm water from a portion of the business section of the city is carried to Thirty-first Street, where a spillway was built to empty a

portion of the flow from above into the river. Of course water flowing over the weir of the spillway will be diluted sewage, but this flow occurs rarely. Twice only during the summer of 1895 did water go over the spillway, and then only for a few hours each time. The construction of the spillway is shown in Fig. 2.

Manholes were built about 400 ft. apart along the whole length of the extension. In the first one below the spillway, 400 ft. down the sewer, a gate was built, which can be lowered at any time and so force over the spillway all the sewage except that entering at Thirty-sixth Street. This gate was in use from January 24th to June 7th, 1895. Its cost, as well as that of the special manhole in which it was placed, is included in the cost per foot of Section 3.

After considerable delay, owing to difficulties of a legal nature which had to be overcome, work was commenced about the middle of August, 1894, under the direct charge of Mr. A. M. Gibson, who perfected an admirable organization of the forces, and remained in charge of the work until December 7th, 1894, when he resigned to go into other business, and was succeeded by the author, who remained in charge until the work was completed in June, 1895.

Construction was carried on through the winter when the weather was not too inclement, thus adding materially to the cost of some portions of the work, principally that of the spillway and of Section 3, but helping out the laboring men of the city when help was badly needed.

The work was divided into sections, the division points being so located that the kind of work on each section was uniform over its whole length. A careful record was kept of all material coming on to the work, showing on which section and for what particular class of work on the section it was used. The foremen made daily reports, showing the disposal of their forces. At the end of each month these daily reports and distribution accounts were checked against the payrolls and bills for material and made to agree with them. A monthly distribution sheet was made up for each section on which work had been done during the month, each section being assigned its proper share of the general expenses (the cost of the engineering force, bookkeeper and watchmen), and as each section was finished, these monthly statements were consolidated into a final statement.

When the work was completed there were fourteen of these final statement sheets which together covered the total amount charged on

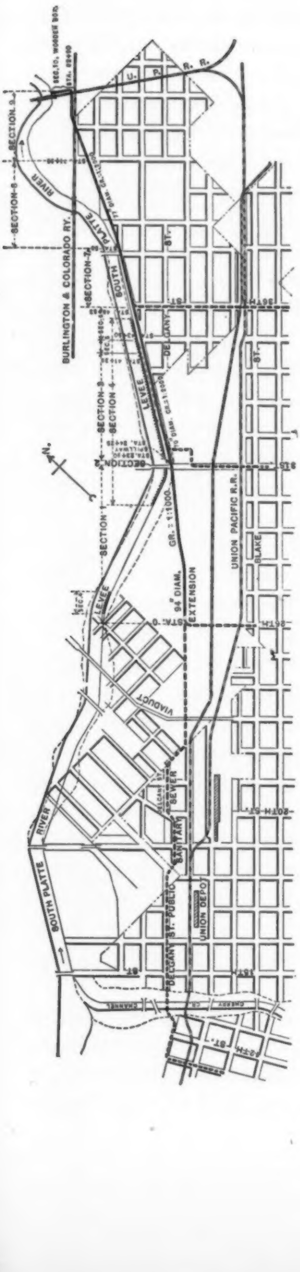
SOUTH PLATTE RIVER
BURLINGTON & COLORADO RY.
UNION PACIFIC R.R.
UNION DEPOT
VIADUCT
LEVEE
BLAKE ST.
DELGANY ST.
SANITARY SEWER
EXTENSION
94" DIAM.
SECTION 1
SECTION 2
SECTION 3
SECTION 4
SECTION 7
SECTION 8
SECTION 9
U. P. R. R.
CHERRY CR.
CHANNEL

Fig. 1.

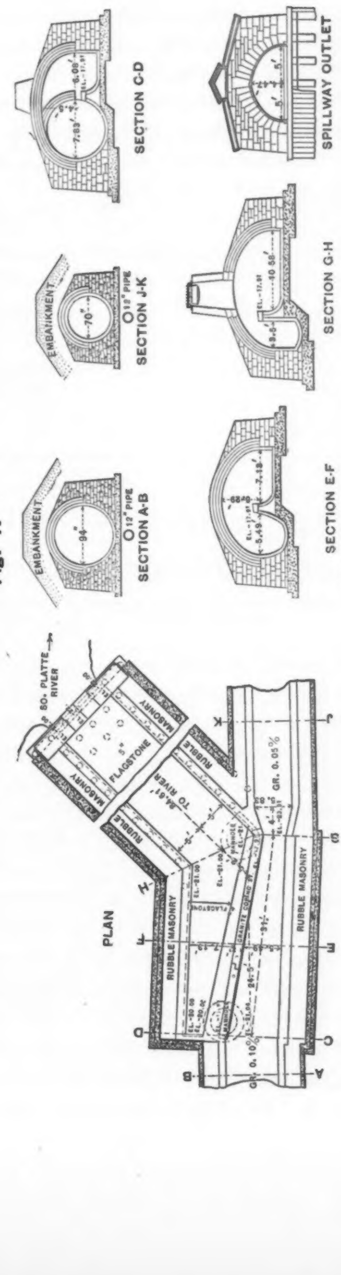
EMBANKMENT
12" PIPE
SECTION A-B
SECTION J-K
SECTION C-D
SECTION E-F
SECTION G-H
SPILLWAY OUTLET
PLAN
SO. PLATTE RIVER
MASONRY
FLAGSTONE
RUBBLE
TO RIVER
RUBBLE MASONRY
GR. 0.05%
GR. 0.10%

Fig. 2.

the city auditor's books to "Delgany Street Public Sewer Extension," up to July 15th, 1895. After that date a small amount may have been added to the account to cover the cost of completing the record maps, etc. The following table shows the amount carried on each sheet, and reference to the map (Fig. 1) will show the sections covered by each sheet, except the minor ones for connections, etc.

Sheet.	Section.	Sewer and Description.	Length.	Cost per foot.	Total cost.
1..	....	Charges against sewer not chargeable to per foot cost	....	....	$16 911 93
2..	....	Extra work on Section 1 outside of net section.	....	....	2 131 41
3..	1	94 ins. diameter, stone cradle	2 393.7	$20.191	48 331 71
4..	2	Spillway	35	....	6 774 70
5..	3	70 ins. diameter, stone cradle	1 714	16.515	28 306 95
6..	4	River protection work	....	....	9 687 90
7..	5	70 ins. diameter, in rock	211	9.41	1 985 69
8..	6	70 ins. diameter, three-ring work, in rock	503	10.816	5 440 61
9..	....	Downing Avenue sewer connection, Thirty-sixth Street	....	....	505 42
10..	7	77 ins. diameter, in rock, three-ring work	947	12.567	11 900 30
11..	8	" gravel, "	1 396	12.292	17 158 65
12..	9	" sand, "	1 094	12.956	14 173 59
13..	....	Consolidation of sheets 10, 11 and 12, average.	....	12.58	....
14..	10	Wooden box, 323 ft. long	....	6.91	2 231 25

Total amount charged to the extension	$165 540 11
Deduct sheet 1	16 911 93
Cost of construction work	$148 628 18
Deduct sheet 14, temporary wooden box	2 231 25
Total cost of 8 293.7 ft. of permanent work, including cost of spillway and protection from river	$146 396 93

The items on Sheet 1, aggregating $16 911 93, while part of the cost to the city of the improvement, are not properly chargeable to the per foot cost of the sewer, being legal charges, cost of preliminary surveys and of work on record maps, expenditures for right of way, etc. Deducting this amount from the total charge of $165 540 11 leaves $148 628 18 as the total cost of construction work, including $2 231 25 spent on a temporary outlet. Deducting this leaves $146 396 93 as the cost of 8 293.7 ft. of permanent sewer, including $9 687 90 spent on a levee some 3 200 ft. long, heavily slagged, to keep the river away from the sewer.

The following brief description of each section is given as explanatory of the conditions under which the work was done.

Section 1, 94 Ins. Diameter, 2 393.7 Ft. Long.—This section was built on ground the original elevation of which averaged a little above invert grade, but which had been filled in with refuse to a depth of from 2 ft. to 5 ft. This filling consisted principally of manure, but was full of tin

cans, wire, old bed springs and the trash which accumulates on a city dump, making the cost of excavation high. The bottom of the trench was from 2 ft. to 4 ft. below the water level in the river close at hand, and the material was coarse gravel, so there was a large amount of water to pump. The back-filling was expensive, as a large proportion of the material had to be hauled in on wagons. While Table No. 1 shows the back-filling less than the excavation, the material taken from the trench was not suitable for covering the sewer.

The section had a concrete base 16 ft. wide and 8 ins. thick, and a stone cradle containing 1.8 cu. yds. per foot of sewer. The invert was a single ring of brickwork, and the top was three rings, except across certain lands where a fourth ring was added. The cost per foot given in the table, \$20 19, is for the three-ring section.

Section 2, Spillway.—The cost of pumping on the spillway was excessive, as the greater part of the work was done in freezing weather, and the floor of the spillway was below water level, so that the pump had to be run night and day during a considerable delay in the delivery of material. Its total cost was \$6 774 70. The throat of the spillway forms 35 ft. of the main sewer.

Section 3, 70 Ins. Diameter, 1 714 Ft. Long.—There was less excavation on this section than on Section 1, and it was nearly all good material to handle, but nearly all in water.

The section built was similar to Section 1, containing an average of 80% as much material per foot as the 94-in. section; 80% of \$20 19 is \$16 15, while the actual cost of this section was \$16 51 per foot. This increased cost was nearly all accounted for by a general increase in prices of material which took place about November 1st, 1894.

Section 4, Levee, About 3 200 Ft. Long.—Nearly the whole of the extension from Twenty-sixth Street to Thirty-fifth Street is on ground which was once the bed of the river. Above Thirty-first Street this low ground had been partially reclaimed by a levee built by the landowners, but at and below this street the line was exposed to the river. To protect the sewer a levee was built. It was some 3 200 ft. long, about 10 ft. high, and with 2 to 1 and 3 to 1 slopes, with 8 ft. crown. The river slope was covered with slag, a trench 3 ft. deep and about 5 ft. wide being first dug at the toe of the slope. This slag averaged 3 ft. in thickness at the bottom and 1 ft. at the top. The cost per foot was about \$3.

Section 5, 70 Ins. Diameter, 211 Ft. Long.—Near the lower end of Section 3 the excavation entered rock which promised to be solid and homogeneous, and Mr. Martin decided to dispense with two rings of brick in the invert, the concrete base and stone cradle being, of course, dropped to bring the excavation, made as near as possible to the proper section, to semi-circular form by concrete and then to put in one ring of brick for the invert. As seen by the cost per foot, $9 41, this was economical, but it was soon found that the rock was not uniform, being full of soft places. This form of cross-section was abandoned after 211 ft. were built.

Section 6, 70 Ins. Diameter, 503 Ft. Long.—Sections 6, 7 and 8 were built in inverse order, work beginning at the lower end of Section 8 on February 21st, and being completed to the upper end of Section 6 on May 10th, or 2 846 ft. of sewer was built in two and one-half months, nearly three weeks of which time was lost by injunction proceedings over right of way. The rock extended the whole length of Section 6, but was very soft in places, being hardly more than an indurated clay. The excavation averaged about 11 ft. in depth, running from 7 to 14 ft. Timbering was used over nearly all of the section. The cross-section was full three-ring work, all brick in the lower half being laid to a line. No water was encountered, and no drain pipe was used. The cost per foot was $10.816.

Section 7, 77 Ins. Diameter, 947 Ft. Long.—The rock extended the whole length of this section, varying in hardness as on Section 6, and was overlaid with loose sand, necessitating timbering over its whole length. The cut averaged 11½ ft. The cross-section was full three-ring work, and the cost per foot was $12.567.

Section 8, 77 Ins. Diameter, 1 396 Ft. Long.—There was no rock on this section, but a large amount of water in sand and gravel, principally the latter. The water was carried into a borrow pit and thence into the river by a side pipe at the lower end of the section. The cut averaged 12½ ft., and timbering was used the whole length. The cost per foot was $12.292.

Section 9, 77 Ins. Diameter, 1 094 Ft. Long.—The material here changed to fine loose sand. The average cut was 14 ft., going up to 17 ft., with considerable water. The line of the sewer on this section crossed four railroad tracks, the worst crossing being on an angle of 22° under the Burlington main track. This track was put on 12 x 12-

in transverse timbers; the excavation was 12 ft. wide and 16 ft. deep in loose sand, and was kept open nearly two weeks, the sewer built and back-filled, and the track put back on the ground without bringing a regular train to a stop. The traffic, however, was rather light, there being only six or seven regular trains each way in 24 hours. Excavation was started May 5th, the first brick was laid May 10th, and the last June 6th, two days of the time between the two dates being lost by rain. The cost per foot was $12.956.

The average cost per foot of Sections 7, 8 and 9, all of the same cross-section, was $12 58. This includes the cost of all lumber bought for timbering and scaffolding, no allowance being made for the value of old lumber left when the work was completed.

Section 10, Wooden Box, 323 Ft. Long.—The lower end of Section 9 is connected with the river by a wooden box 3½ x 3½ ft. in the clear, laid on a heavy grade, the intention being to carry the brick sewer ultimately some 6 000 or 7 000 ft. further northeast, where the invert grade line will reach the surface and there may be a chance to sell the water for irrigation. The box was put in place before work on Section 9 commenced, and a 12-in. drain pipe laid under the box carried the ground-water away from Section 9. The excavation for this box was deep, averaging 16 ft., and about one-fourth was rock, clay marl, with much water. There is a reef of this clay marl, mingled with layers of soft sandstone, all along the river front from Thirty-fifth Street down. Sections 6 and 7 lie in the reef, but Sections 8 and 9 are back of it, and Section 10 cuts through it. This accounts for the large amount of water encountered so close to the river and at an elevation above its level, this reef acting as a dam to hold back the ground-water flowing from the south.

The following tables are self-explanatory when studied in connection with the description of each section.

TABLE No. 1.—MATERIALS PER FOOT OF SEWER.

Material.	Sec. 1.	Sec. 3.	Sec. 5.	Sec. 6.	Sec. 7.	Sec. 8.	Sec. 9.
	Cu. yds.	Cu. yds.	Cu. yds.	Cu. yds.	Cu. yds.	Cu. yds.	Cu. yds.
Excavation—Earth	3½	1¼	1.2	3.0	4.0	5.5	7.0
" Rock	....	....	1.5	1.4	1.4	....	....
Concrete	0.395	0.349	0.15	....	....	....	....
Stone masonry	1.8	1.25	....	....	....	....	....
Brick "	0.753	0.588	0.583	0.885	0.967	0.967	0.967
Back filling	2.4	3.2	2.7	4.4	5.4	5.5	7.0

TABLE No. 2.—Cost per Foot of Main Sewer.

	Section 1. 94 ins. diameter. 2 393.7 ft.	Section 3. 70 ins. diameter. 1 714 ft.	Section 5. 70 ins. diameter. 211 ft.	Section 6, 70 ins. diameter. 503 ft.	Section 7. 77 ins. diameter 947 ft.	Section 8 77 ins. diameter. 1 396 ft.	Section 9. 77 ins. diameter. 1 094 ft.	Sections 7, 8 and 9. 77 ins. diameter. 3 437 ft.
Excavation	$ .891	$ .377	$1.236	$1.412	$2.058	$1.620	$1.766	$1.787
Pumping—Draining	.743	.595	....	....	.078	.484	.282	.308
Concrete base	1.925	1.645	.635	....	....	....	....	....
Stone cradle,	8.128	6.134	......	....	....	....	....	....
Brickwork	6.443	5.761	5.722	8.324	9.332	9.203	9.396	9.300
Back-filling	.832	.842	.347	.223	.357	.301	.822	.482
Engineering	.715	.663	.916	.572	.500	.463	.420	.460
Tools	.424	.320	·381	.150	.097	.100	.140	.112
Watchman, etc	.090	.178	.173	.134	.145	121	.130	.131
Total	$20.191	$16.515	$9.410	$10.815	$12.567	$12.292	$12.956	$12.58

TABLE No. 3.—Cost per Cubic Yard of Concrete.

Material.	Sec. 1. 946.6 Cu. Yds.		Sec. 3. 598 Cu. Yds.		Average, 1 544.6 Cu. Yds.	
	Quantity.	Cost.	Quantity.	Cost.	Quantity.	Cost.
Portland cement (K., B. & S.)	.756 bbl.	$2.61	.7 bbl.	$2.44	.732 bbl.	$2.543
Crushed rock	.777 cu. yd.	1.40	.72 cu. yd.	1.42	.754 cu. yd.	1.409
Sand	.470 "	.165	.35 "	.125	.424 "	.148
Water	....	.01	....	....	....	.007
Labor	....	.685	....	.73	....	.703
Total	....	$4.87	....	$4.715	....	$4.81

The cement was all Portland, and the proportions of the concrete 1, 3 and 6. If Louisville cement had been used in the proportion of 1, 2 and 5, this cost would have been decreased about $1 35 per cubic yard, making the average about $3 46. This does not include tools, pumping or engineering.

The broken stone was unscreened, crushed sandstone, paid for by the cubic yard, but on an agreed basis of 2 500 lbs. for a cubic yard, the car weights being taken. There was no dirt in it, but many small pieces, the largest being about the usual 2-in. ring size.

TABLE No. 4.—COST PER CUBIC YARD OF STONE CRADLE.

MATERIAL.	SEC. 1. 4 295 CU. YDS.		SEC. 3. 2 143 CU. YDS.		AVERAGE, 6 438 CU. YDS.	
	Quantity.	Cost.	Quantity.	Cost.	Quantity.	Cost.
Rubble stone.............	1.3 tons.	$1.965	1.29 tons.	$1.995	1.297	$1 975
Cement....	.848 bbl.	1.175	.93 bbl.	1.43	.875	1.261
Sand....	.292 cu. yd.	.115	.33 cu. yd.	.16	.305	.13
Water	....	.005	....	.005	....	.005
Labor	....	1.27	....	1.315	....	1.284
Total......................	....	$4 53	....	$4.905	....	$4.655

This does not include pumping, tools or engineering. The stone was bought by the ton, car weights being taken. It was sandstone easily worked, and, as shown by the amount used per cubic yard, of a low specific gravity. It was admirably adapted to the work where great strength was not needed, but rather a stone working easily under the hammer. A little Portland cement was used for plastering the top of the spandrel wall during cold weather, but nearly all was Louisville cement bought in paper sacks, 265 lbs. to the barrel. The mortar was mixed 2 to 1.

TABLE No. 5.—COST PER CUBIC YARD OF BRICKWORK.

MATERIAL.	SECTION 1. 1 800 CU. YDS.		SECTION 3. 1 009 CU. YDS.		SECTION 5. 123 CU. YDS.		SECTION 6. 445 CU. YDS.		SECTIONS 7, 8, 9. 3 325 CU. YDS.		AVERAGE, 6 702 CU. YDS.	
	Amount.	Cost.	Amount.	Cost.	Amount.	Cost.	Amount.	Cost.	Amount.	Cost.	Amount.	Cost.
Brick, number	438.3	$4.07	431	$4.89	439	$4.58	450	$4.71	439.6	$4.75	438.9	$4 584
Cement, barrels..........	.835	2.01	1	2.365	1.07	2.63	.87	1.71	.939	1.81	.919	1.953
Sand, cubic yards	.34	.15	.35	.175	.375	.19	.42	.21	.46	.23	.408	.198
Miscellaneous.	......	.31	......	.365	.....	.17	......	.085	......	.16	.....	.229
Labor..........	......	2.025	......	1.985	.....	2.25	......	2.695	......	2.66	.....	2.384
Total......	......	$8.565	......	$9.78	.....	$9.82	......	$9.41	......	$9.61	.....	$9.348

Portland cement mortar mixed 3 to 1 was used in laying the inner ring of brick on the whole work and for plastering on Section 3, where the top was nearly all put on during freezing weather. The

Louisville cement mortar used on the rest of the brickwork was mixed 2½ to 1 on Sections 1, 3 and 5, and 3 to 1 on Sections 6, 7, 8 and 9. If Louisville had been used in place of the Portland, the average cost per cubic yard of $9 35 would have been reduced to about $8 70. This price does not include tools, except centers and templets, pumping or engineering, but does include all manholes, both special and regular, including manhole steps, covers and rings.

TABLE No. 6.—Detail Cost of Brick Work on Sections 7, 8, 9.—Cost per Cubic Yard.

Material.	Section 7. 916 Cu. Yds.		Section 8. 1 349 Cu. Yds.		Section 9. 1 060 Cu. Yds.		Average, 3 325 Cu. Yds.	
	Amount.	Cost.	Amount.	Cost.	Amount.	Cost.	Amount.	Cost.
Brick, number	442	$4.81	440	$4.70	438	$4.765	439.6	$4.75
Cement, barrels	.937	1.835	.99	1.91	.876	1.655	.939	1.81
Sand, cubic yards	.484	.24	.44	.22	.47	.235	.46	.23
Miscellaneous	....	.135	....	235	....	.09	....	.16
Labor	....	2.63	....	2 465	....	2.95	....	2.66
Total	....	$9.65	....	$9.53	....	$9.695	....	$9.61

The miscellaneous item in Tables Nos. 5 and 6 is for slants, manhole covers, steps and rings, templets and centering and water.

TABLE No. 7.—Total Days' Labor Performed, including Levee and all Extra Work.

Occupation.	Wages paid.	Days' work.	Remarks.
Foreman	$3 33⅓ to $5 00	726	
Stone masons	$3 60	1 398	4.7 cubic yards rubble masonry average day's labor.
Brick "	4 00	1 491	2 080 brick laid, equal 4.7 cubic yards brick masonry per day.
Labor (including watchmen).	2 50	385	Watchmen, blacksmith and timbermen.
Labor	2 00	8 115	
Labor	1 75	7 628	
Water boys	$1 00 and $1 25	363	
Man and team	$3 50	2 150	
Engineers and pumpers	3 00	252	

All for an eight-hour day except pumpers, who were paid $3 for 10 hours' work, but generally worked 12 hours.

PLATE II.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XXXV, No. 773.
FOLLETT ON COST OF DENVER SEWERS.

The appliances used were of the most ordinary kind; all concrete was mixed by hand and put in place with shovels and wheelbarrows; the brick and mortar were lowered by hand ropes into the deep trenches from platforms in the usual manner.

The wages paid to all classes of labor employed, both skilled and common, were about 40% above the average rates in force when the work commenced. It is beyond the scope of this paper to enter into a discussion of the motives which led the Board to set so high a scale of wages. Suffice to say, the wages shown were paid, and members can easily make the necessary allowances when comparing the cost of this work with that of contract work where different rates of compensation are in force.

Mr. Martin perfected a very neat steel ring used for centering. Plate II shows the construction pretty clearly. The ring consists of two semi-circles of about 8-lb. steel, a section being taken of a height equal to the thickness of the lagging to be used. The lower half is bent to form with the flange toward the center, its outer radius being that of the invert. The upper half is bent with the flange out, its radius being that of the lower half, less the thickness of the lagging. To each end of the lower half is riveted a short piece of the same section of rail with a hole punched in the flange, a corresponding hole being punched in each end of the upper half. One of these pieces has its upper end cut on a slight bevel, corresponding to a similar bevel on the end of the upper semi-circle. The two halves are joined by two lugs and bolts at each end. The lagging used was dressed out of 2 x 4-in. stuff with radial joints, and dressed on both sides. Each piece had fastened to its lower side three little iron clips, each one being held in place by two wood screws. The end of each clip was bent away from the wood just the thickness of the flange on the steel ring. It is frequently the case in perfecting a new appliance that some minor part of the device causes all the trouble. In this case the devising of a means to attach the lagging to the rings was the difficult point. Several plans were tried and abandoned, but finally this clip was suggested. It solved the problem and made the combination a complete success. Five rings were used to each 12-ft. length of lagging, so that forty rings sufficed to set up 96 ft. of centers.

In use, when ready to knock down a length of centering, the workmen removed the bolts from the pair of lugs at the bevel joint of a

ring, struck the latter a sharp blow with a hammer, and collapsed the joint. The three intermediate rings were first removed, then the end ones knocked out, and the lagging released. The collapsed rings were dragged forward through the 84 ft. of centering already in place, and set up again and bolted. The lagging was brought forward, thoroughly cleaned in the joints, and put in place, one piece at a time, a slight shove endwise engaging the clips on the rings, and an occasional sixpenny wire nail driven on the opposite side of the ring keeping the strips from working loose. The last piece of lagging wedged the whole section together, and the outside of the section was scraped clean with a shovel and wet down.

When building 96 ft. of top per day, two men would take down, clean and set up this centering, besides doing some cleaning in the finished sewer, making the cost of moving a little less than 4 cents per foot. In building the 8 290 ft. of sewer, three sets of rings and two sets of lagging were used, costing (including bolts, screws, clips and labor) about $775, or 9.3 cents per foot ; or the whole cost of centering, including moving, was a little over 13 cents per foot of sewer built. Of course, where the diameter of a sewer changes frequently, new rings would be required for each diameter, and the cost per foot increased. On this work the sizes were 70, 77 and 94 ins. only, and so but three sets of rings were used.

DISCUSSION.

HENRY GOLDMARK, M. Am. Soc. C. E.—In railway work the conditions are usually somewhat unlike those in city work, but the conclusions derived from experience are not very different. Contract work is more desirable and cheaper as a rule than work by the day, but there are two cases where the latter is preferable. One is when there are conditions which are not fully understood before beginning operations, so that the contractor is obliged to charge for a considerable element of risk and uncertainty. The second case occurs when an especially good grade of work is required, as this can be obtained more cheaply by day labor under the engineer's direct superintendence than it can under very good inspection, where it is done under ordinary contract conditions. Mr. Goldmark.

In one or two instances the speaker had found it advisable in every way to supply sand and cement in large quantities to the contractor and allow him to use it freely under some supervision, rather than to specify the amount of cement and sand and allow the measuring to be done with the idea of using the exact amount specified. On one occasion, when a number of abutments, piers and arched culverts were constructed on a railway, about half were built by contract and half by day labor, under the speaker's supervision. The cost of the work was nearly the same under both methods of construction, but the quality of the work done by day labor was decidedly better, although the contractor made but a very small profit on his work.

With regard to the high wages mentioned in the paper, the rates of \$1 75 and \$2 a day for common labor were exactly what were paid in Eastern Kansas and Southwestern Missouri on the railway work mentioned previously, although the railway company was paying only \$1 10 for the ordinary track force. For \$1 75 a day a gang of about twenty negroes was secured, who were exceptionally strong and vigorous men, and more than earned the extra amount they were paid per day by their superior efficiency in excavating heavy soil for foundations and in mixing concrete. The force account showed that the cost per cubic yard of excavation and of concrete was less than it had been under the contractor's method, employing men at \$1 25 a day. This case shows forcibly that high-priced labor gives cheap results if it is carefully selected and carefully watched. It was the speaker's experience that where an engineer is not overburdened with work and is able to give the proper amount of time to a close daily supervision of the construction and has a perfect competent inspector on duty all the time, who can do essentially the work of a foreman, a high grade of masonry can be secured for a sum which would only give an average quality of work at contract prices.

Mr. Crowell. FOSTER CROWELL, M. Am. Soc. C. E.—The importance in all work, whether done by contractors or under the direction of engineers, of keeping a full and accurate force account of the details of the undertaking is obvious, and the paper gives an illustration of particularly careful supervision in this particular. The desirability of having work done by day labor under the direction of engineers or by contractors must depend upon the special conditions of each problem. There are some cities in which the contract system is the only one that should be adopted at the present time, but there are others where the work done by day labor would show a great saving and serve as an object lesson as to what can be accomplished at a reasonable cost. Any city where the same opportunities are given as in Denver could secure equally good results without any very great difficulty, and if the facilities for transporting material are more favorable the results will be better. Most cities began their public works by the day labor plan, but have been forced to adopt the contract system in self defence. The latter has improved in this country in many respects, and where the contractor has not been allowed to have too much latitude, the results are certainly excellent. Whether work is done by contract or not, the paper contains a valuable lesson to engineers who have this kind of work in charge, that they will obtain much better results by keeping this elaborate and troublesome kind of a force account. The results justify it, and the city will be the gainer, whether the accounting is only for the purpose of finding out what such an undertaking actually costs, or to show the citizens what are the detailed expenses of work performed properly.

Some years ago the speaker had under his supervision a number of contractors who were building a railway. One morning it was found that the contractors on seven or eight sections had abandoned the work and left the State. The railway company had either to relet the sections, which would have taken considerable time and trouble, as the work was in all stages of advancement, or to carry it on by day labor. The latter plan was adopted, and one of the first steps was to have the engineer corps previously employed see that the work was done properly. The plant left by the contractors was put in use, somewhat improved perhaps, but in general in the condition in which it had been abandoned. All members of the engineering party were instructed to keep an accurate account of what the men were performing. They made their entries from time to time during the day in their field books, and reported in connection with their engineering work; this force account was simply a record of what the men on different classes of work were performing. In a short time the work was systematized, and a few months later the books showed a considerable profit on the balance of the work on which the contractors had lost money. As construction progressed, the interest of the men in the

engineer corps continued to increase, and those in charge of different sections became quite emulous of one another in securing the best results. There was a very decided profit to the railway company arising from the interest which was awakened in that way. Mr. Crowell.

On other occasions the speaker had undertaken for a company work which could not be very clearly specified, owing to peculiar circumstances, and therefore could not be put under contract unless the contractor obtained a sufficiently high price to cover the risk. Sometimes the railway company preferred to take the risk itself, and probably saved money in the end; sometimes it lost money. In such cases it is extremely important for the engineer corps to have a knowledge of what men can accomplish in different classes of work, and what is a fair day's work under the particular conditions.

The speaker agreed with Mr. Goldmark, that there was often a real economy in paying high wages to secure good results. Men vary much in their capacity to do work as well as in their intention to do it, and men who feel they are well paid and know they depend on their performance to retain their positions will accomplish much more than those who receive simply the market price for labor. If the engineer has the authority to discharge men when they fail to do their work, there is generally no extravagance in paying a good price.

George R. Hardy, M. Am. Soc. C. E.—The advantage of doing work by contract lies in the fact that the contractor undertakes to accomplish the most work at the lowest price, and when he has named his price per unit for each class of work to be executed, the company or municipality has a clear conception of how much per unit the undertaking will cost, let the classes of work be more or less in amount. If unforeseen conditions arise, the company or municipality has to pay the cost of meeting them, for a contractor cannot be expected to gamble, so to speak, on whether or not there is rock in the excavation or the excavation will be unusually deep; he names a price at which he can probably carry out each item in the contract, while the corporation pays more or less than estimated for each class of work, according as the total quantities of each class exceed or fall below the estimates. Under this method of doing work, the duty of the engineer corps is confined to securing satisfactory results from the contractor. In this way the contractor has to bear the expense of forcing the men to work properly, and no expense is entailed upon the corporation on this account. For this reason the contract system is the best method of accomplishing large engineering undertakings where the magnitude of the work is so great that the engineer cannot personally supervise its execution. Mr. Hardy.

Accounting by a regular system for all expenses is a matter all engineers desire to investigate thoroughly, but accounting can be carried so far as to become too expensive. In the work mentioned in the

Mr. Hardy. paper the expense of accounting and engineering seems to have been combined, for 50 cents, 75 cents or 71 cents is given as the cost of engineering. If the engineering includes accounting, and there is a large force of clerks on the work so as to carry out the accounts in considerable detail, it will soon be found that the cost of this clerical work will far exceed its proportional advantage. If the work is done under an engineer able to see the relative importance of all the details, he will be able to obtain from day to day the reports necessary for a proper distribution of the total expenditure.

CORRESPONDENCE.

Mr. Landreth. WILLIAM B. LANDRETH, M. Am. Soc. C. E.—The paper is valuable as furnishing a means of comparing the cost of sewer work built by day labor in an inland city with that done by contract. Tables Nos. 3, 4 and 5 are of interest as showing the quantities of material and labor in each unit of finished work, and ought to be useful to persons estimating on such work. The cost of some of the material, especially the brick, is greater than the ruling prices east of Chicago, as would be expected, and the paper explains the reason for the excessive cost of the labor. The following statement, compiled from the tables in the paper, shows the cost per cubic yard of excavation, pumping and back-filling on the several sections.

Section	1	3	5	6	7	8	9
Cost	$0.734	$1.451	$0.541	$0.372	$0.462	$0.437	$0.410.

The paper shows that the cost for Section 1 was increased by the excessive quantity of water encountered, but the reason for the high cost of Section 3, $1.451, is not clearly stated. The cost of Sections 7, 8 and 9 indicates that the rock was not hard, as is stated in the paper. On sewer work done by contract in several eastern cities and towns under the writer's direction, the average cost for excavation, pumping and back-filling has been 30 cents per cubic yard. The work was on both pipe and brick sewers in earth and soft rock, with cuts from 6 to 20 ft. deep, and where the contractor made a profit. On other sewer work where the contractor bid an average of 19 cents per yard and abandoned the contract when the cuts reached 16 ft. to 18 ft., the municipality completed the work by day labor at a cost for excavation, pumping and back-filling of 63 cents per yard. The work was in loose gravel, with water and quicksand in places, and was carried on with the same men the contractor had employed. The work cost the contractor as much as it did the municipality, and the case is cited

only as an instance of a contractor naming a price much below actual cost. Mr. Landreth.

The writer's experience has been that sewer work generally costs a city less by contract than by day labor. A study of the number of days' labor employed on the Denver work indicates that the force was well handled, and the amount of labor per unit of completed work was a fair average of that on similar work in other places. The question as to whether the Denver work could not have been done for less money with some form of a trench machine suggests itself, but a correct answer probably depends upon some local conditions not stated in the paper. The paper indicates that a permanent, solid construction was desired, and the evident care with which the work was looked after by the engineer probably secured that result.

Andrew Rosewater, M. Am. Soc. C. E.—Having had occasion to become acquainted with the features of the Delgany sewer through an engagement to report upon the original project, the writer visited the work twice during its construction and can say that it is one of the best pieces of mechanical sewer construction he ever saw. The iron rails supporting the lagging on the arch were very convenient and simple, and, as they were handled, there were no connecting lines of sectional work to be seen on the entire line of the sewer. The brick used was exceptionally good and the courses were laid to perfect lines throughout; this was to be expected to a certain extent on work done by day labor. The marked feature in the management was the absence of incompetent mechanics and shiftless workmen, which was due to the fact that the board, in its desire to demonstrate the practicability of doing work better and cheaper by day labor than by contract, placed the construction in the hands of engineer experts with exclusive authority to employ and discharge men, and this authority was rigidly exercised, according to the writer's observation. The tabulated results as to cost do not show any striking gain over that of contract work in this case, but assuming the cost to be the same as under the contract system, the material and workmanship are decidedly better than under that system. This is one of a few instances where experiments of this kind have been successful. In probably seven cases out of ten the political tendencies of boards made up wholly of scheming politicians to give sinecures to political hangers on, would have largely increased the cost of the work without securing any compensating benefits in quality of material or workmanship. Mr. Rosewater

L. J. Le Conte, M. Am. Soc. C. E.—The actual cost of any piece of engineering work depends largely upon local circumstances, and it is hard to draw comparisons which will have much weight between the day labor and contract systems. If a city happens to have a competent engineer with experience in the line of work contemplated, and the plant required to execute the work is small and inexpensive, then Mr. Le Conte.

Mr. Le Conte. there is no doubt that the city can save possibly 25% on the cost of the work by hiring the necessary labor, purchasing the materials and doing the work itself. On the contrary, if the plant required to do the proposed work is expensive and of a permanent nature, it is generally more economical for the city to let the work out by contract, due regard being given to developing a healthy competition. The chief reason for adopting contract work is to avoid keeping an expensive plant on hand after the completion of the work, which experience shows to represent so much dead capital, the interest on which increases rapidly. Any attempt to sell the plant always ends in a disastrous sacrifice. The actual cost of concrete on this sewer is given as $4 81 per cubic yard in place, which is certainly creditable for hand-mixed concrete. The actual cost of coursed rubble masonry side-walls and invert, $4 66 per cubic yard in place, is surprisingly cheap and hard to understand. In this class of work rubble masonry will generally cost much more than concrete. The author gives the cost of arch brickwork as $9 34 and $9 61 per cubic yard in place. This stands out in bold contrast to the cost of other work, and naturally suggests the propriety of using concrete for the arches and confining brickwork to the inverts where scour is likely to take place. Inasmuch as there were 10 000 cu. yds. of brickwork and only 1 545 cu. yds. of concrete used, the possibility for further economy seems to be worthy of consideration.

Mr. Nelles. G. T. Nelles, M. Am. Soc. C. E.—The author gives a very complete analysis of the cost of his work, and makes a good showing for the day-work system. In considering his results it should be borne in mind that this work was not done under the conditions that usually exist on city work, but under intelligent engineering supervision, free from political influences. It was in fact a test piece of work, for it was only after a long and bitter contention between the Board of Public Works and the City Council of Denver that it was decided to do the work in this manner. It is not necessary here to go into the reasons that prompted the board to do the work by the day, but it is sufficient to say that it had ample political reasons for the step. Having in the face of great opposition decided to build the sewer by hired labor, the board realized that it was necessary to make a record, and also to redeem the promises made in its arguments during the discussion of the matter. It went about the accomplishment of this object in a manner quite unusual with political bodies, and from the start recognized the fact that its wishes could only be attained through its chief engineer. Acting under his advice it employed an intelligent superintendent, an engineer experienced in this particular class of work, and gave him almost absolute authority in all matters pertaining to the construction of the sewer. By this action it was possible for the superintendent to do the work in practically the same manner, and at about the same cost that it could have been done by contract.

Under such conditions public work can be done at a minimum cost. Mr. Nelles. The trouble will not be so much in doing the work, as in securing proper conditions. Another important factor in the cost of work done under proper supervision in this manner by cities, is the fact that they do not enter into a binding contract with themselves to do the work in a fixed manner, and under rigid specifications, as is the case when work is done by contract. On the contrary they are always at liberty to make such change in methods or materials as experience may prove to be beneficial and economical to the work. Under the contract system it is rarely possible to make such changes, no matter how desirable they may be, without raising a cry of fraud or violating some of the terms of the contract. As a consequence whenever there is a choice of materials or methods under the contract system, the most expensive to the contractor is usually adopted.

The author states that the wages paid were high and that due allowance should be made for this in using his figures. It is the writer's experience that within reasonable limits nothing is lost by paying good wages. This is particularly the case where work is scarce, and where employment is due to merit rather than influence. An examination of the scale of wages paid on this work shows that common labor was paid more and skilled labor less than the current rates in Denver one year previous to the construction of the sewer. It would naturally be expected that this would increase the cost of work done by common labor and decrease the cost of that done by skilled labor, but it is shown by a comparison with the cost of similar work in the same locality, done under the writer's supervision and under a different scale of wages, that the reverse is true, and that the amount of work done per man varies in about the same proportion as the wages paid.

It is the writer's opinion that in most cities public work can be done to better advantage and at less cost by contract than by hired labor, and that while the author's work is a good example of the latter system, his results are far more favorable than can usually be obtained.

The form of centers used for constructing the arch is in many ways a great improvement over the centers in common use. They are light and easy to move and set up, and leave the interior of the sewer free from obstructions during the construction of the arch. The cost of this form of centers seems to be excessive and would make their use prohibitive on sewers of shorter lengths and varying sizes.

W. W. Follett, M. Am. Soc. C. E.—The work of keeping the Mr. Follett. detailed accounts was not onerous. The executive force on the work consisted of the engineer in charge, one assistant engineer, three rodmen, one bookkeeper and two to four foremen. Prior to January 1st, 1895, there was also a superintendent of supplies and a cement inspector, but on that date both were discharged. The bookkeeper kept the general time-book, and made up the pay rolls and pay checks,

Mr. Follett. in addition to keeping the regular book accounts of supplies furnished. A laborer acted as brick inspector under the direct supervision of the engineer in charge, and reported to the bookkeeper each night the distribution by sections of the day's delivery. The foremen stated on their daily reports the amount of cement and sand used on each section. The engineer in charge usually took the first Sunday of each month on which to make up the distribution sheets for the previous month, and he consolidated the monthly sheets of each section into the final one on stormy days or evenings, so that the system of distribution did not cost the city anything over the usual cost of supervision of similar work. The cost per foot for engineering varied considerably on the different sections, because the progress of the work was not equally rapid on all sections, while the cost of engineering, being the salaries of the engineer corps and bookkeeper, was practically constant.

It was not the intention of the author to intimate that the wages paid were too high. This work was started when there was no demand for labor and wages were badly demoralized. Mr. Nelles is in error in saying that skilled labor was paid less than it was one year previous to the construction of this sewer extension. During the summer of 1893 there was absolutely no demand for skilled labor. He probably had in mind two years before, when sewer bricklayers were paid $6 to $7, and stone masons $4 per day. The bricklayers did not lay as many brick per man on this work as they had formerly done when working for contractors, not because they were paid less for their labor, but because they were required to lay the brick carefully, as stated by Mr. Rosewater. While they had received $6 per day two years before, the wages for bricklayers elsewhere in the city at the time this work was under way were about $2 50. The bricklayers were receiving as large pay, and had the same incentive to work, as the laborers, and it is quite true that men will work better when paid good wages, especially when they know that time checks are filled out in the office on very slight provocation. By means of the discipline thus enforced one foreman handled 18 bricklayers, divided into three gangs, the total number of men on his force, including helpers and laborers, being 80. The foreman of stone masons handled about as many, while the trench foreman sometimes had 100 in his gang. After the pace had been set and the quality of work wanted was thoroughly understood by the men, there was no difficulty in getting standard work. The average mechanic prefers to do good work.

In this connection the author wishes to call Mr. Hardy's attention to the fact that the foremen on this work were only about half as many in number as the inspectors would have been had the work been done by contract, while the other executive force was the same, with the addition of a bookkeeper.

Mr. Follett

The rock in the trench was not hard, except in a few places. As stated in the description of Sections 6 and 10, it was very soft. Mr. Landreth is mistaken in his statement in that respect, and if he will examine Table No. 1, he will also see that there was no rock on Sections 8 and 9, as stated in his correspondence.

With reference to the cost of excavation, pumping and back-filling, while in deep trench work it may be quite appropriate to lump these three items and charge them all to the cost per cubic yard of excavation, on work like that under consideration, this process is misleading. For instance, on Section 3 there was but 1¼ cu. yds. excavation per foot, or, the excavation being 15 ft. wide, the average cut was about 2.2 ft., nearly all of which was in water. A 12-in. drain pipe, costing 31 cents per foot, was carried over this section. The back-filling amounted to 2.4 cu. yds. per foot, nearly all of which was hauled either by wheelbarrows, wagons, or wheel scrapers, the earth thrown out of the trench being left where it fell, to form the haunches of the back-filling. It is manifestly improper to add the cost of all of these items together and divide the sum by the amount of excavation, as Mr. Landreth has done.

The principal reason why the rubble masonry cost less than the concrete is that the former was made with Louisville cement, while Portland was used in the latter. Had Portland been used in the rubble, its cost would have been about $5 90 or $6 a yard. The stone used broke square in the quarry, so that very little hammering was required in the trench, while the foreman in charge had a peculiar ability for handling material with few laborers. These conditions account for the low cost of the rubble masonry.

The question of substituting concrete for brickwork in the arch of a sewer, broached by Mr. Le Conte, is one admitting of much argument on both sides, and the author will not attempt to discuss it here any further than to say that the cost per cubic yard of concrete in an arch would be considerably more than in a flat bed.

Two factors enter into the consideration of the question of whether a city should do work by contract or by day labor, viz., the probable relative cost of the two methods, and the quality of work likely to result from each. The average contractor is in the business to make a profit, while frequently his work is handled by an engineer, the same as it should be if the city did the work. Unless the work requires an expensive plant, it seems reasonable to believe that the city, under the same management, can save at least a portion of the contractor's prospective profit. About two years prior to the beginning of the extension under consideration, the city had built by contract that portion of the Delgany sewer above Twenty-sixth Street. The 1 400 ft. immediately above Twenty-sixth Street is 92 ins. in diameter, and has the same cross-section as was used on Section 1. When the latter section was completed, the author made a very careful and elaborate analysis of the

Mr. Follett. cost to the city of the two prices of work, and he found that when due allowance was made for the difference in cost of labor and material, Section 1 would have cost the city some $26 50 per foot, including inspection and supervision, if it had been let by contract on a basis of the contract prices in force above Twenty-sixth Street, as against its actual cost of $20 19. This indicates a saving of about 25% resulting from the day labor plan. In the case under consideration the contractor has pending in the courts a claim against the city, a quite frequent aftermath of contract work, a portion of which he will eventually collect, and this will add materially, probably $2 or more, to the cost per foot of the contract work.

Every engineer appreciates the extreme difficulty of forcing the average contractor to comply fully with the specifications when so good an opportunity offers for successful scamping as there does in sewer work. Mr. Rosewater has mentioned the quality of work done on this extension. It seems to the author that it must always be much easier to obtain good work by day labor than by contract. Hence, even if no saving in cost results to the city, the better quality of work obtainable should incline city authorities to the day labor plan. The author does not understand why, as stated by Mr. Nelles, the results as to cost here given are better than can usually be obtained. Any body of city officials can, if it chooses, divorce politics from business, and make the construction of the public works under its charge a strictly business proposition, as was done on the Delgany sewer. Men competent to handle work can be found by city authorities as easily as by contractors, and the city can go into the market and buy materials about as cheaply as can the contracting fraternity.